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Relationships between impervious surfaces and surface water quality in Hunnicutt Creek watershed, Clemson, South Carolina

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RELATIONSHIPS BETWEEN IMPERVIOUS SURFACES AND SURFACE WATER QUALITY IN HUNNICUTT CREEK WATERSHED, CLEMSON, SOUTH CAROLINA.

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ABSTRACT

Hunnicutt Creek watershed drains to the eastern edge of Clemson University campus. The landscape of this part of campus changes from a natural park like botanical garden to one dominated by academic buildings. The campus area has changed in time as well with increasing impervious areas such as roads, parking lots, roof tops and decreasing the amount of forested land leaded to the impairment of water quality in this creek. The objectives of this study were to evaluate the relationships between water quality indicators and percent imperviousness at a watershed level. Eight sampling sites were assigned at each sub-watershed within the Hunnicutt Creek watershed. Each sub-watershed was evaluated for the percent imperviousness and a variety of water quality indicators including physical, chemical and biological parameters. The correlation between the imperviousness and these water quality parameters was determined. The results indicated the mean percent imperviousness within study site was 21%. The values of habitat score and water quality parameter (pH, dissolved oxygen, conductivity and nitrate) were significantly different among sub-watersheds. Also, macroinvertebrate matrices showed the significant differences among sub-watershed sampled sites. Percent imperviousness showed significant correlations with habitat scores, dissolved oxygen, conductivity, fecal coliform bacteria, taxa richness, EPT richness, biotic indices and percent oligochaeta at p-values ≤ 0.05. The headwaters of Hunnicutt creek, upstream of the McMillan road and the academic zone tended to be more impacted than the headwaters within the South Carolina botanical garden.

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CHAPTER I

INTRODUCTION

Alteration of land surface for human use is one of the major sources of change in watersheds. Development of the land for human habitation has resulted in increased impervious surfaces such as roads, parking lots, roof tops, etc., and a decrease in the amount of forested lands, wetlands, and other forms of open space that absorb and clean storm water in natural systems. This increase of impervious surfaces has caused significant changes to the quality and quantity of the storm water runoff, leading to degraded stream and watershed systems (Brabec et al., 2002). Stormflows have resulted in increased total suspended solids and concentrations of dissolved copper, lead and zinc, and decreased dissolved oxygen (Tsegaye et al., 2006). Nutrient and fecal coliform concentrations within watersheds with impervious surfaces of more than 5% often exceeded those in undisturbed watersheds and fecal coliform bacteria in more urbanized areas often exceed the USEPA's standard for recreational waters (Schoonover et al., 2005).

Removal of streamside vegetation and subsequent increased solar radiation reaching the stream channel can increase temperature and alter thermal regimes that are critical to the life history and ecology of macroinvertebrates (Wang and Kanehl, 2003). Macroinvertebrate community assemblages have been used by EPA as indicators of the biotic integrity of stream ecosystems. Macroinvertebrate communities have shown trends of decreased abundance and total species diversity with increasing urbanization (Gray, 2004). Macroinvertebrate indices have been shown to be most closely related to land-cover patterns. The differences in macroinvertebrate assemblage structure has been explained by land-cover patterns when appropriate spatial scales were employed (Sponseller et al., 2001).

Preliminary studies of Hunnicutt Creek watershed on the campus of Clemson University indicated that the macroinvertebrate community assemblage was impacted by the land usage within this watershed. These preliminary studies were simple macroinvertebrate surveys and lacked the scientific vigor to test for differences between the sub-watersheds of Hunnicutt creek and the relationship of the macroinvertebrate community to the watershed land use.

Objectives

The objectives of this study were to evaluate the relationships between water quality indicators and percent imperviousness at a watershed level.

Specific objectives were:

1. Determine macroinvertebrate community metrics and other water quality parameters at eight different stream reaches in the Hunnicutt Creek Watershed.

2. Determine percent imperviousness for each sub-watershed associated with the sampled reach.

3. Determine the relationship among sub-watershed land use and macroinvertebrate community metrics and water quality parameters.

Hypothesis

1. H_o: Water quality is not different among sub-watershed sample sites.

   H_A : Water quality is different among sub-watershed sample sites.

2. H_o: Percent imperviousness is not different among sub-watersheds.

   H_A: Percent imperviousness is different among sub-watersheds.

3. H_o : Relationship among sub-watershed land use and macroinvertebrate community metrics and water quality parameters are not different.

   H_A : Relationship among sub-watershed land use and macroinvertebrate community metrics and water quality parameters are different.

CHAPTER II

STUDY AREA

Watershed description

Hunnicutt Creek Watershed (HCW), 7,129,936 square meter, is located in the southern outer Piedmont within the Tugaloo/Seneca River basin (HUC: 03060101) in Pickens County, Northwestern South Carolina. The watershed is mostly within the boundaries of the Clemson University campus (Figure 2.1).

The watershed has greatest elevation in the eastern part of the area which covers South Carolina Botanical garden, Kite Hill and a campus residential zone. Maximum elevation is approximately 840 feet. The area where there is the greatest concentration of academic buildings, between Highway 93 and Perimeter Road, is relatively flat. The elevations drop to the west except for the hillock, which is Woodland Cemetery. South of Perimeter Road, the land continues to slope down toward the edge of the Lake Hartwell.

The land use types within this watershed are composed of residential, academic building, and recreation zone (Walker Golf Course and Botanical Garden). The watershed area has been impacted in the past by many agricultural uses.

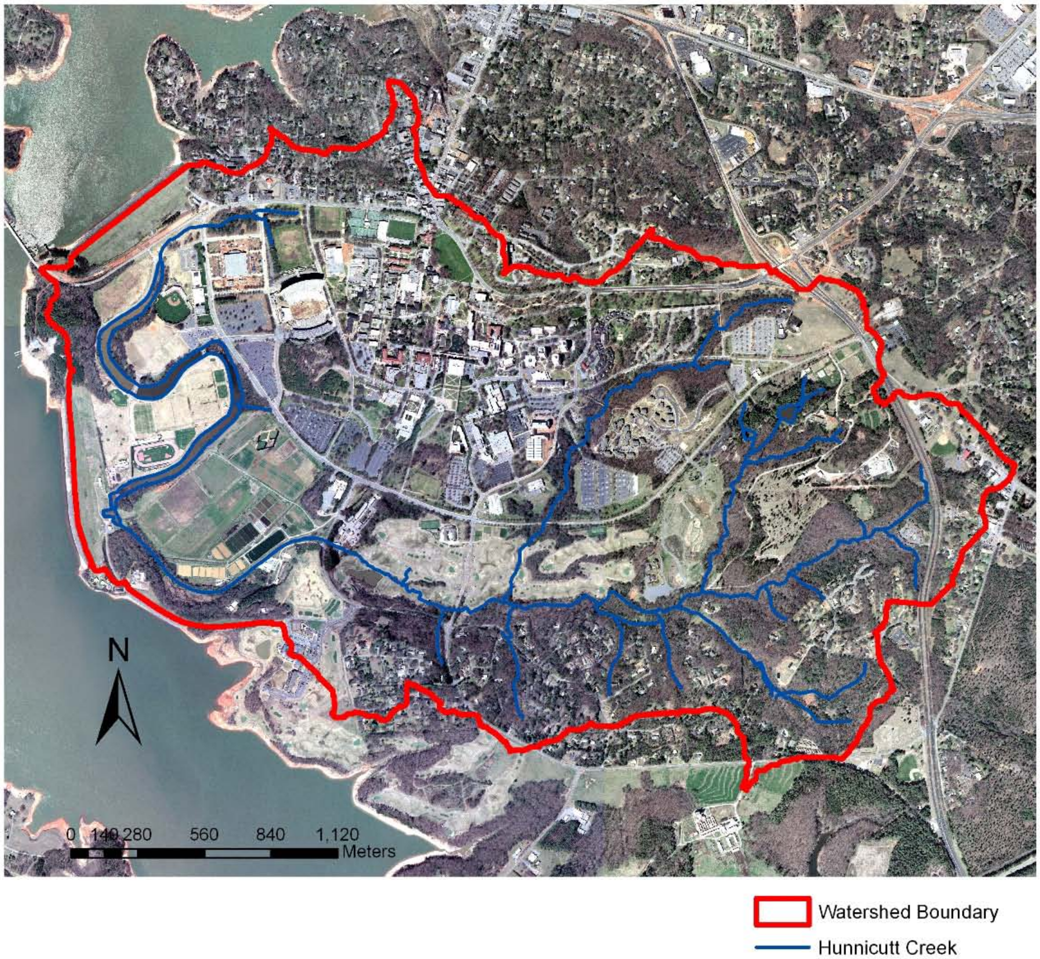

Figure 2.1 Hunnicutt creek watershed boundary.

CHAPTER III

METHODS

3.1 Land Use Evaluations

Land uses were classified into two categories: pervious and impervious surface areas. A geographical information system (GIS) (ArcGIS 9.2; ESRI, Redlands, CA, USA) was used to evaluate pervious and impervious areas within each sub-watershed. Twenty foot contour lines for Clemson city was obtained from South Carolina Department of Natural Resources (SCDNR) web site. Two foot resolution of orthophoto of Clemson University campus (2002) was obtained from Pickens County GIS mapping.

The Hunnicutt Creek Watershed and each sub-watershed boundaries were delineated by hand using the twenty foot contour lines. Pervious and impervious surface areas were classified by hand based on orthophoto to determine total contributing area for each sub-watershed.

3.2 Water Quality Assessment

Eight water quality monitoring sites, separated throughout each sub-watershed, were selected from the Hunnicutt Creek Watershed (Figure 3.1) as follows:

Site 1	In Hunnicutt Creek upstream of Old Stadium Road within Clemson facilities.
Site 2	In Hunnicutt Creek above the confluence of the Lightsey Bridge branch.

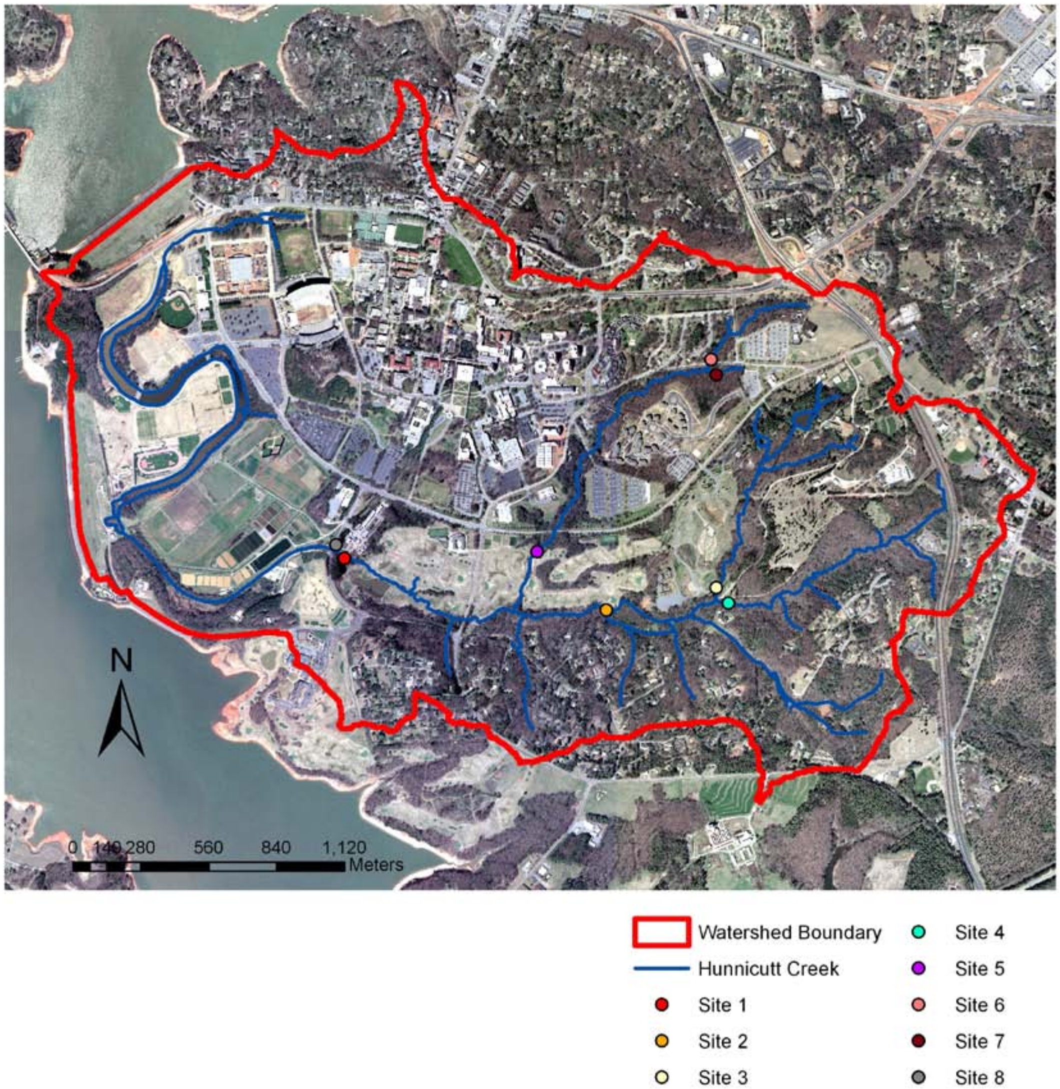

Figure 3.1 Water quality monitoring sites. Red line is watershed boundary for all of waters flowing through Clemson. Hunnicutt Creek watershed boundary is shown in figure 4.1

Site 3 and Site 4	North fork and south fork of Hunnicutt Creek within the South Carolina Botanical Garden
Site 5	Upstream of Perimeter Road on Lightsey Bridge branch.
Site 6 and 7	Upstream of McMillan Road on Lightsey Bridge branch (left and right).
Site 8	Within Clemson facilities which receive storm water from the academic zone.

Each site was sampled by season in June (summer), September (fall), December (winter) and March (spring) starting in 2007 and ending in 2008.

3.2.1 Habitat Analysis

At each site, habitat data were collected by using the Rapid Bioassessment Protocols Habitat Assessment (RH) approach (Barbour et al., 1999). RH scores are based on visual assessment of 10 habitat parameters, with scores ranging from 0 for poor condition to 20 for optimal condition for each component. Evaluation and scoring of each component is based on comparison to descriptions provided in four condition categories (optimal, suboptimal, marginal and poor) that encompass a range of scores. Low gradient stream habitat criteria were used for evaluation due to the gradient condition of the Hunnicutt Creek.

3.2.2 Physical/Chemical Parameters.

Measurements of dissolved oxygen (DO), conductivity, pH and water temperature during normal (non-storm) flows were taken at the time of habitat analysis and macroinvertebrate and fecal coliform sampling at all 8 sites.

Dissolved oxygen was determined with a YSI® Model 58 (YSI, Yellow Springs, OH, U.S.A.) handheld dissolved oxygen meter. Conductivity was measured with a YSI® Model 30 portable conductivity meter. Water temperature and pH was measured with Beckman® Model 255. Nitrate and phosphate were measured with SMART® colorimeter (LaMotte Company). All meters were calibrated in the lab prior to sampling.

3.2.3 Biological Parameters

Fecal coliform and macroinvertebrates were used as biological indicators of water quality.

3.2.3.1 Fecal coliform

Samples were collected from surface water and bottom sediment. Each surface water sample was collected in a sterile 250 ml Nalgene Polypropylene bottle without disturbing the bottom sediment. Each sample was stored on ice for transport to the laboratory. Bottom sediment samples for each site were collected by using a sterile sample aspirator. The sediment sample was collected by turning the aspirator horizontally with the bulb compressed and gently removing the top 1-2 cm of sediment while moving the aspirator. At each water sampling site, a combined sediment sample was taken. The combined sediment sampling site was approximately 1 square meter with the surface water sampling site as the center. The initial sediment sample was taken from the bottom sediment directly below the surface water sampling site. Three additional bottom sediment samples were taken within the 1 square meter. All 4 samples were combined in the same sterile sample bottle. Each sample bottle was placed on ice for transport to the laboratory (Jolley, 2005).

All sites were sampled on the same day and all samples were analyzed within 6 hours of collection. Fecal coliform analyses were conducted in a South Carolina Department of Health and Environmental Control certified laboratory using Method 9222 D (Fecal Coliform Membrane Filter Procedure) from Standard Methods for the Examination of the Water and Wastewater (APHA, 1998). Fecal coliform values were reported as colony forming units (CFUs)/100 mls and was referred to as CFUs in the text. Each bottom sediment sample was shaken by hand for one minute and the supernatant was sampled immediately for fecal coliforms. Fecal coliform analysis was performed as for surface water samples. Sediment volumes were measured by allowing the sediments to settle for 24 hours in a graduated cylinder. Sediment levels of fecal coliforms were calculated as CFUs of sediment for ease of comparison with surface water values (Jolley, 2005).

CFUs of surface water were calculated as follows:

$$\text{CFUs} = \frac{C}{D} \times 100$$

Where:

D = volume of sample diluted

C = CFUs on plate

CFUs of sediment were calculated as follows:

$$(C/D \times TV) - (CW/100 \times WV) = A$$

$$A/SV \times 100 = \text{CFUs}/100 \text{ ml sediment}$$

Where:

C = CFUs on plate

D = volume of sample diluted

CW = CFUs surface water

TV = Total volume of water and sediment

WV = volume of water

SV = volume of sediment

A = Total CFUs in sediment

CFUs values were $\log_{10}$ transformed to overcome the heterogeneity of variances before correlations were applied.

3.2.3.2 Macroinvertebrates

Aquatic macroinvertebrates were used to assess water quality and biotic integrity of Hunnicutt Creek. A 1 ft^2 area of the benthos in front of the 500 µm D-frame net was agitated for approximately 10 minutes. Aquatic macroinvertebrates drifting from the agitated area were collected in the net. Three replications from the 8 different sites were taken in riffles. Each replication sample was placed in a zip-lock plastic bag, and stored on ice.

Samples were returned to the lab and preserved with 80% ethyl alcohol. Samples were placed in a white pan. All macroinvertebrates found were removed from the white pan and placed in a jar containing 80% ethyl alcohol for preservation.

General references used for identification are Merrit & Cummins (1996), Ciegler (2003), Needham et al. (2000), Westfall et al. (1996) and Wiggins (1996). Each macroinvertebrate was identified to the taxonomic level of genus except Chironomidae. Chironomidae was identified to family level only. Individual taxa were assigned a pollution tolerance value based on North Carolina Biotic Index (NCBI). The NCBI may be adjusted for mountain, piedmont, or coastal ecoregions of the southeastern United Stated (Lenat, 1993). The NCBI is calculated as:

$$NCBI = \frac{\text{Sum } (TV_i)(N_i)}{N}$$

Where TV_i is the tolerance value of the i^{th} taxon, N_i is abundance value of the i^{th} taxon (1, 3 or 10), and N is sum of all abundance values. Metric scores produced with biotic index ranged from 0 dominated by highly intolerant taxa to 10 dominated by highly tolerant taxa.

In addition to the biotic index, EPT taxa richness was used as a metric for water quality. EPT richness measures the number of taxa in the EPT orders. EPT orders (Ephemeroptera, Plecoptera and Trichoptera) are sensitive to stream perturbations and are used by various water quality monitoring agencies. Final bioclassification, as used by SCDHEC, is calculated by giving an equal weight to both the NCBI value and EPT taxa richness value in assigning bioclassifications. The two values were then averaged together, and rounded up or down to produce the final classification. Final bioclassification were classified as interpreted into 1 = Poor, 2 = Fair, 3 = Good-Fair, 4 = Good, and 5 = Excellent.

In addition, other macroinvertebrate community metrics used to evaluate water quality included, total numbers of individuals which is the measurement of the overall abundance of organisms identified, taxa richness which is the measurement of the overall variety of the macroinvertebrate assemblage, % Chironomidae, and % Oligochaeta.

Statistical Analysis

SPSS version 16.0 was used to compare each site and season value. A one-way ANOVA using the least significant different (LSD) test statistic was used to determine if the season and site sample collected were associated with significant differences in each parameter (p values $\leq$ 0.05)

SPSS version 16.0 was used to determine the correlation (R) of the water quality metrics in each sub-watershed to percent imperviousness with p values ≤ 0.05.

CHAPTER IV

RESULTS

4.1 Land Use Analysis

Percent imperviousness of the subwatersheds associated with each sample site varied considerably in Hunnicutt Creek watershed (Table 4.1, Figure 4.1). Average percent imperviousness for all Hunnicutt Creek was 21.65. The headwaters of Hunnicutt Creek (sites 3 and 4), located in the South Carolina Botanical Garden had the lowest percent of impervious areas (9 and 13% respectively). The headwaters of the Lightsey Bridge branch (sites 6 and 7) which were primarily composed of parking lots had the highest percent of impervious area of the headwaters (23 and 45% respectively). Site 8 had the most academic buildings and the greatest percent imperviousness (50.72%).

Table 4.1 Percent imperviousness in sub-watersheds upstream of each site.

Site ID	Impervious Area (m^2)	Total Area (m^2)	% Imperviousness
1	622,358	3,757,580	16.56
2	216,701	1,956,407	11.08
3	55,796	580,331	9.61
4	91,496	684,017	13.38
5	312,898	995,006	31.45
6	33,423	143,789	23.24
7	31,764	70,130	45.29
8	333,858	658,243	50.72

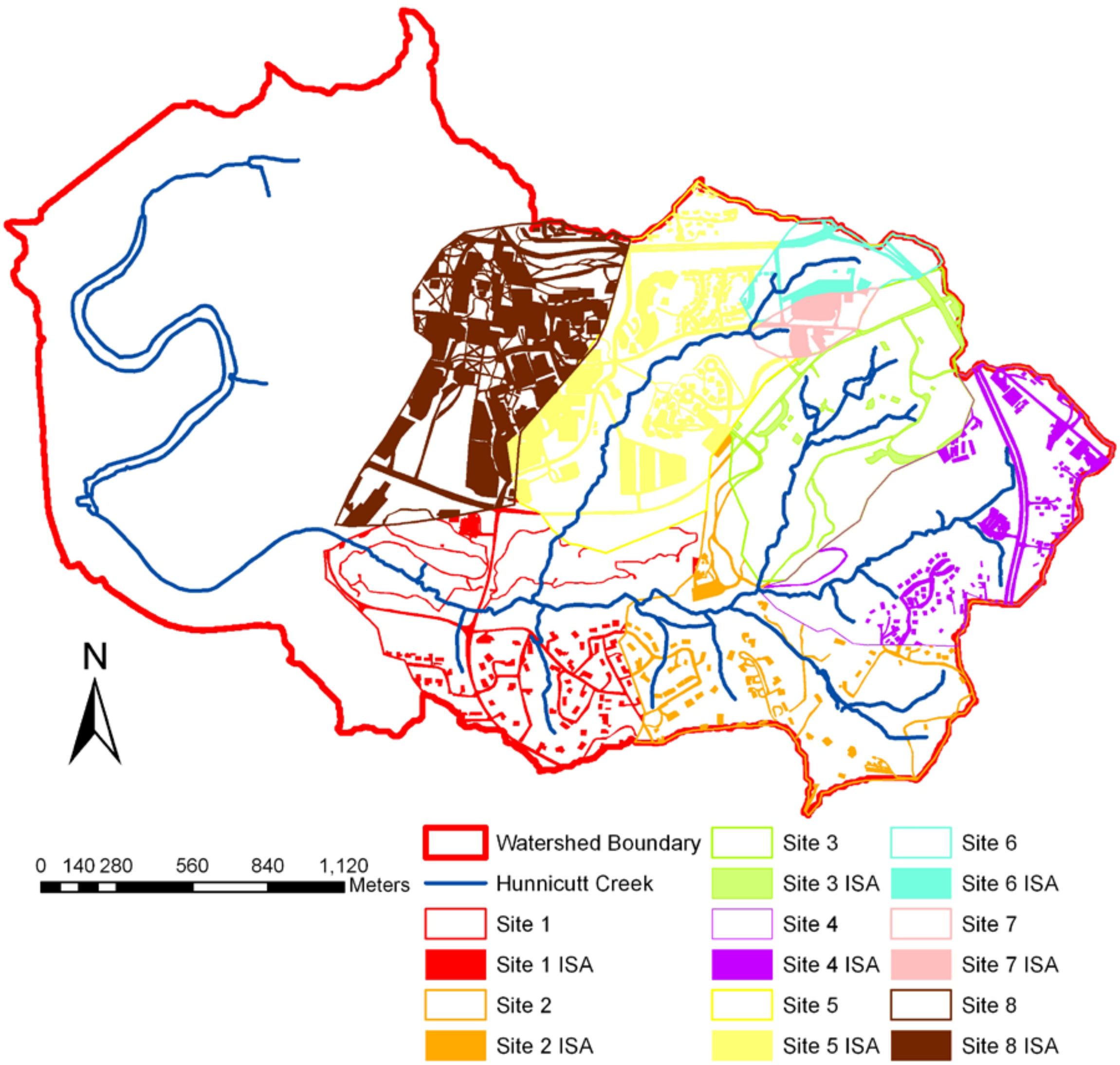

Figure 4.1 Impervious surface areas (ISA) within the study area.

4.2 Water Quality Assessment

4.2.1 Habitat Analysis

Habitat scores showed some variability between sites and seasons. Tests for differences between sites showed habitat scores were significantly higher in sites 2, 3 and 4 than in sites 1, 5, 6, 7 and 8 with p value ≤ 0.05. These data indicated that one of the upstream sites (7), downstream sites (1) and a tributary (8) near the most downstream site had the poorest habitat values (Table 4.2).

Table 4.2 Habitat Score based on visual assessment of 10 habitat parameters: provided by site for each season and mean for year. The total possible score is 200 points. Sites with the same letter were not different from each other at p-values ≤0.05.

Site ID	Habitat Scores				Mean	Std. Dev.
	Summer 07	Fall 07	Winter 07	Spring 08		
1[a]	95.0	90.0	87.0	98.0	92.5	4.9
2[b]	144.0	134.0	140.0	154.0	143.0	8.4
3[b]	134.0	144.0	123.0	145.0	136.5	10.3
4[b]	134.0	130.0	121.0	129.0	128.5	5.4
5[c]	108.0	113.0	119.0	123.0	115.8	6.6
6[c]	107.0	97.0	111.0	121.0	109.0	9.9
7[a]	97.0	90.0	83.0	92.0	90.5	5.8
8[a]	85.0	75.0	81.0	87.0	82.0	5.3

Percent imperviousness had a significantly negative correlation with habitat scores at p-values ≤ 0.05 ($R = -0.87$) (Figure 4.2).

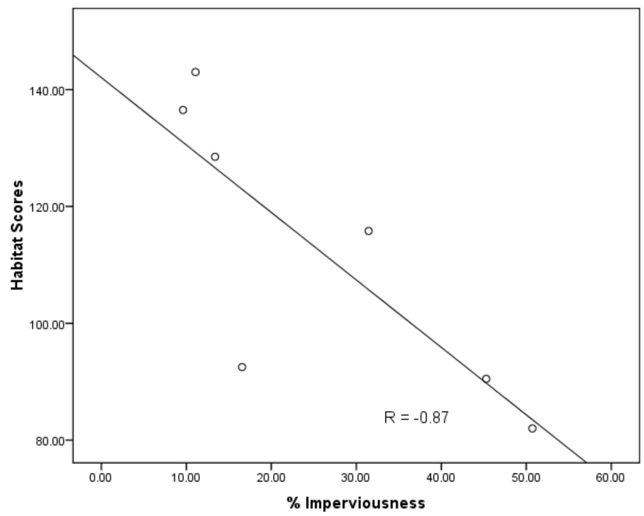

Figure 4.2 Relationship between percent imperviousness and habitat scores in Hunnicutt Creek Watershed.

4.2.2 Physical and Chemical Analysis

Differences among sites were reflected in some of their water parameters (Table 4.3). Temperature values were not significantly different among the sites. The average of pH values ranged from 6-7. pH at sites 3 and 4 were significantly higher than other sites. D.O. was significantly lower at sites 7 and 8. D.O. measured from other sites was not different. Conductivity values were significantly highest at site 8 and lowest at site 2 while other sites were not different. Phosphate-phosphorus values were not significantly different among all sites.

Nitrate-N values were significantly highest at site 7, moderate at sites 1, 2, 5 and 8 and lowest at sites 3 and 4.

Table 4.3 Means followed by (range) of chemical parameters at each sampling site from summer, fall, winter and spring. Sites with same letter in each parameter were not different from each other at p-values ≤ 0.05.

Site	Temp. (°C)	pH	DO (mg/L)	Conductivity (µS)	Phosphate (ppm)	Nitrate (ppm)
1	15.85^{a} (11.5-21.2)	6.63^{a} (6.4-6.9)	9.38^{a} (9.0-9.7)	88.75^{a} (87-92)	0.24^{a} (0.01-0.87)	0.62^{a} (0.58-0.69)
2	16.08^{a} (13.7-20.7)	6.64^{a} (6.5-6.8)	9.13^{a} (8.9-9.4)	68.55^{b} (53-96)	0.05^{a} (0 -0.09)	0.40^{a} (0.26-0.48)
3	15.95^{a} (11.7-21.5)	7.06^{b} (6.3-7.5)	8.90^{a} (8.7-9.0)	88.38^{a} (84-102)	0.10^{a} (0.02-0.24)	0.18^{b} (0.12-0.23)
4	16.03^{a} (13.2-21.7)	7.42^{b} (6.6-8.1)	8.88^{a} (8.7-9.2)	88.48^{a} (78-93)	0.05^{a} (0.01-0.10)	0.26^{b} (0.08-0.41)
5	15.85^{a} (11.9-20.7)	6.80^{a} (6.6-7.0)	8.95^{a} (8.4-9.4)	89.35^{a} (75-95)	0.03^{a} (0-0.08)	0.52^{a} (0.32-0.67)
6	n/a	n/a	n/a	n/a	n/a	n/a
7	17.65^{a} (14.7-20.7)	6.53^{a} (6.1-6.9)	7.40^{b} (6.2-8.3)	95.60^{a} (90-103)	0.04^{a} (0.01-0.06)	0.93^{c} (0.75-1.08)
8	15.95^{a} (11.7-21.1)	6.22^{a} (6.0-6.6)	5.93^{c} (4.7-7.4)	126.78^{c} (110-134)	0.08^{a} (0.03-0.12)	0.46^{a} (0.40-0.60)

- Temperature

Percent imperviousness had a positive correlation with temperature (R = 0.47), but was not significant at p-values ≤ 0.05 (Figure 4.3).

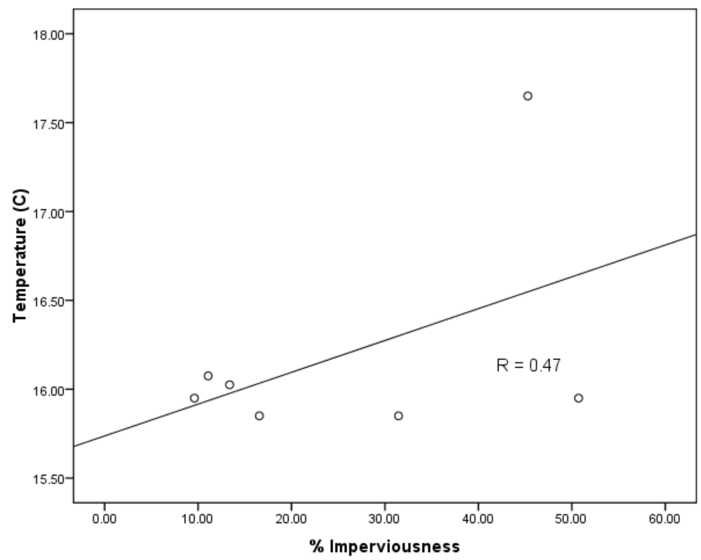

Figure 4.3 Relationship between percent imperviousness and mean surface water temperature.

- pH

The percent imperviousness had a negative correlation with pH (R = -0.69), however it was not significantly at p-values ≤ 0.05 (Figure 4.4).

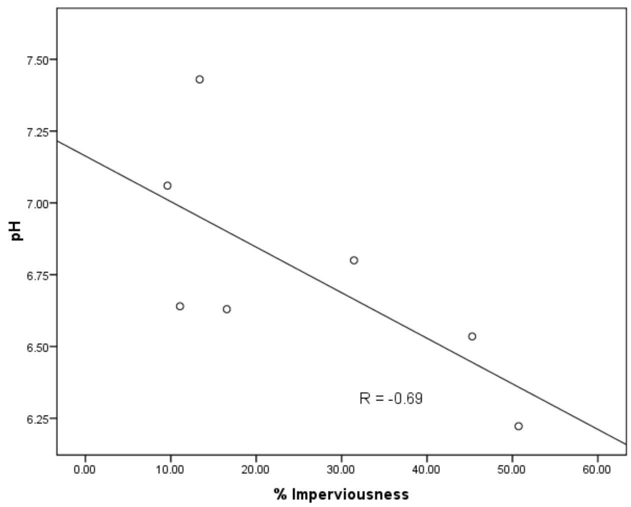

Figure 4.4 Relationship between percent imperviousness and mean pH.

- Dissolved oxygen

The correlation analysis indicated that percent imperviousness had a significant negative correlation with D.O. (R = -0.87) at p-values ≤ 0.05 (Figure 4.5)

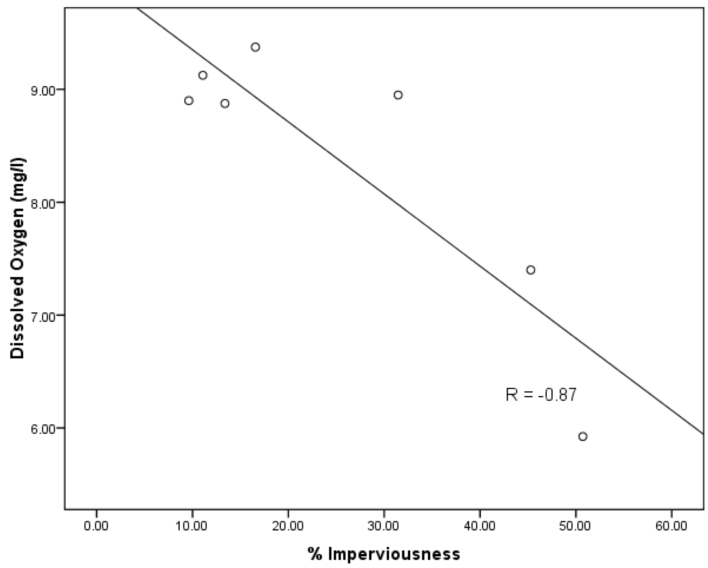

Figure 4.5 Relationship between percent imperviousness and mean D.O.

- **Conductivity**

Mean conductivity (µS) was significantly correlated with percent imperviousness ($R = 0.78$) at p values ≤ 0.05 (Figure 4.6).

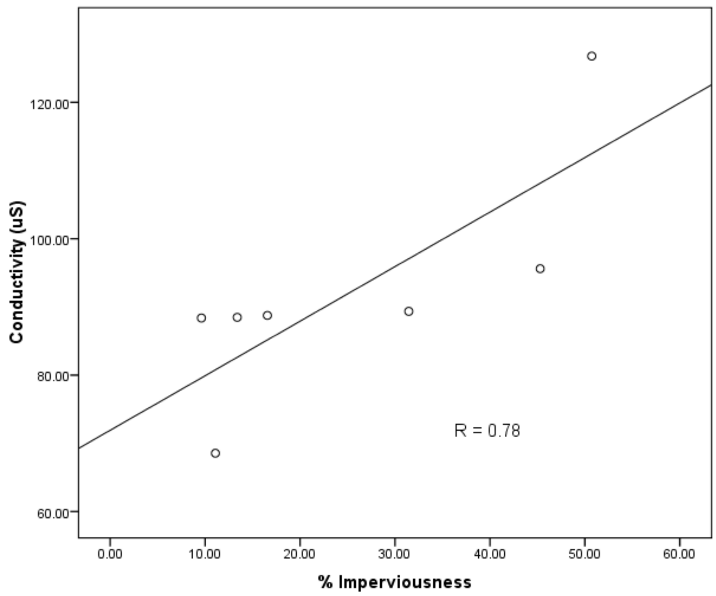

Figure 4.6 Relationship between percent imperviousness and mean conductivity (µS).

- Phosphate

Mean phosphate (ppm) did not have a significant correlation with percent imperviousness at p values ≤ 0.05 ($R = -0.27$) (Figure 4.7). However, it was interesting that site 3, which has the lowest percent imperviousness (9) and located in the SC botanical garden, had a relatively high mean phosphate value. It might be interpreted that site 3 was contaminated by fertilizers that were used in the botanical garden.

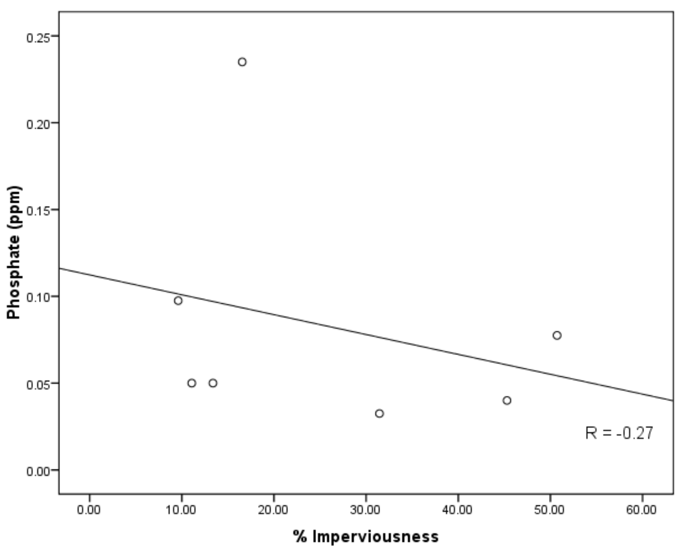

Figure 4.7 Relationship between percent imperviousness and mean phosphate.

- Nitrate

Percent imperviousness was a positively correlated with nitrate (R = 0.63) but not significantly at p-values ≤ 0.05 (Figure 4.8).

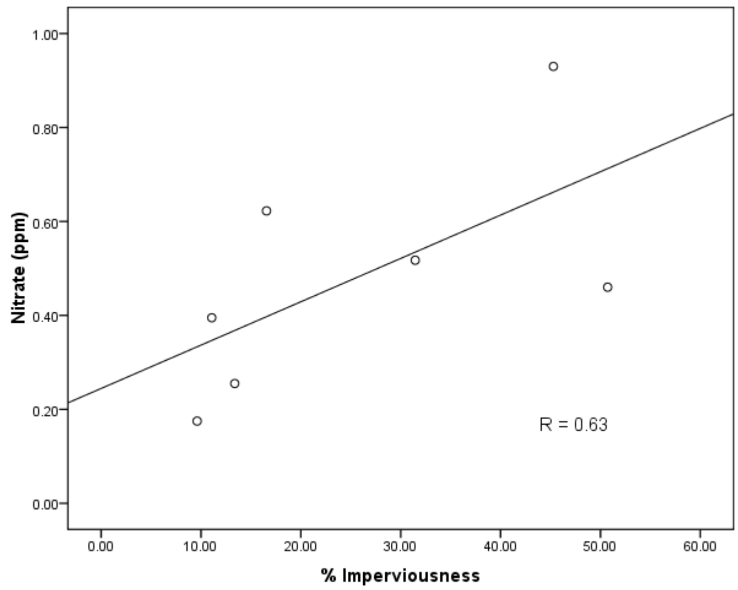

Figure 4.8 Relationship between percent imperviousness and mean nitrate.

4.2.3 <u>Biological Analysis</u>

4.2.3.1 Fecal coliform

Means CFUs among sites in surface water were not significantly different from each others at p-values ≤ 0.05. However, these values were higher in summer for every site.

Mean CFUs of bottom sediment were not significantly different among sites at p-values ≤ 0.05. Mean CFUs of bottom sediments were at least 200 times higher than mean CFUs in surface water.

Table 4.4 Coliform bacteria (CFUs/100ml) in surface water and sediment sampled from summer, fall, winter and spring. The surface water and sediment of each site with same letter were not different from each other at p-values ≤0.05. SCDHEC standard is below 200 CFUs/100 ml.

Site ID	Coliform Bacteria (CFUs/100ml)									
	Summer 07		Fall 07		Winter 07		Spring 08		Mean	
	Surface Water	Sediment	Surface Water	Sediment	Surface Water	Sediment	Surface Water	Sediment	Surface Water	Sediment
1	4,500	2,476,500	800	297,800	300	80,467	220	107,584	1,455[a]	740,588[a]
2	3,000	1,553,400	600	275,800	200	60,950	100	53,140	975[a]	485,823[a]
3	3,500	734,750	1,800	65,600	270	328,710	170	63,926	1,435[a]	298,247[a]
4	3,000	1,285,667	700	194,200	200	177,000	150	123,117	1,013[a]	444,996[a]
5	5,000	1,684,000	900	564,900	300	83,550	290	136,907	1,623[a]	617,339[a]
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7	7,000	1,887,000	800	941,600	300	92,700	370	197,785	2,118[a]	779,771[a]
8	14,200	4,919,200	1,700	1,048,117	150	157,150	420	195,792	4,118[a]	1,580,065[a]

Log transformation of mean CFUs/100 ml in surface water showed a significantly correlation to percent imperviousness (R = 0.89) at p values ≤ 0.05 (Figure 4.9).

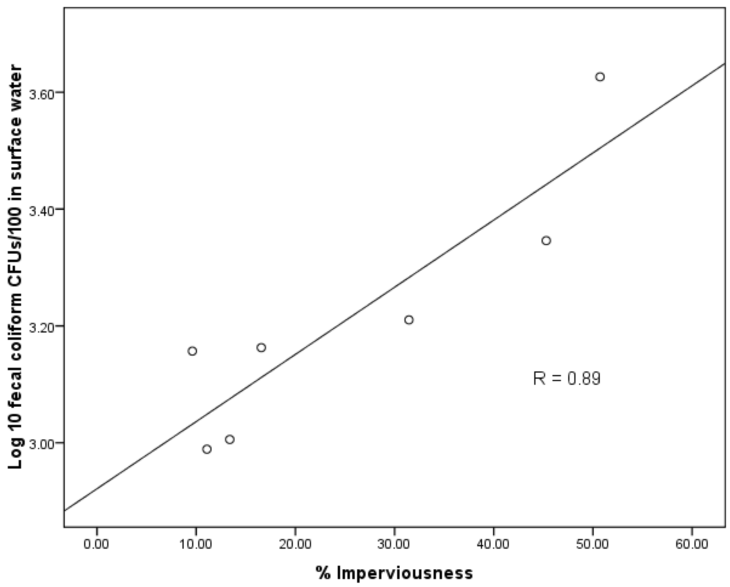

Figure 4.9 Relationship between percent imperviousness and log transformed of fecal coliform (CFUs/100) in surface water.

Log transformation of mean CFUs/100 ml in sediment water was also significantly correlated to percent imperviousness (R = 0.85) at p values ≤ 0.05 (Figure 4.10)

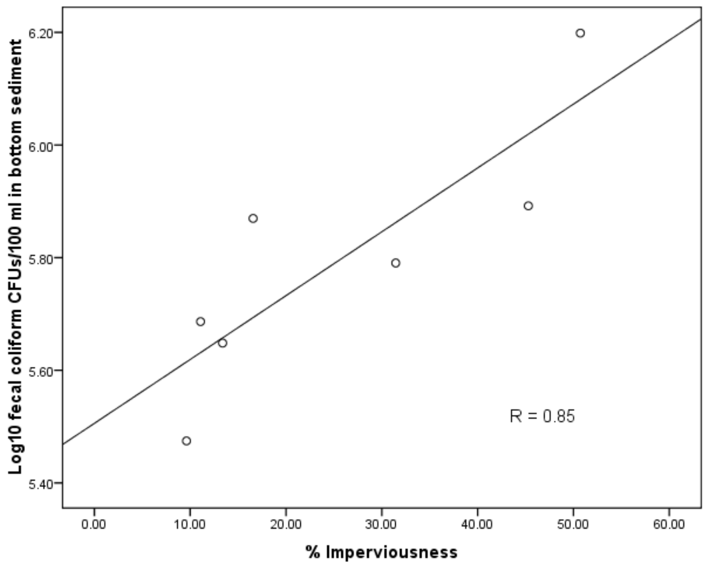

Figure 4.10 Relationship between bottom sediment and log transformed fecal coliform (CFUs/100).

4.2.3.2 Macroinvertebrates

- Total number of individuals

Mean total number of individuals ranged from 43.7 (site 7) to 181.4 (site 3). Site 3 was significantly the highest and site 7 was significantly the lowest in mean total number of individuals at p-values ≤0.05. Sites 2, 4 and 5 as well as site 1 and 8 were not significantly different from each other at p-values ≤ 0.05.

Seasonality significantly affected the total number individuals. The total number of individuals sampled from summer and spring were significantly higher than fall. Winter samples were variable (Table 4.5).

Table 4.5 Total number of individuals in Hunnicutt Creek sampled from summer, fall, winter and spring. Sites with the same letter were not different from each other. Seasons with the same number were not different from each other.

Total Number of Individuals										
Site ID	**Summer 07**		**Fall 07**		**Winter 07**		**Spring 08**		**Average**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1^{a}	88.0^{1}	7.9	48.7^{2}	8.6	61.0^{2}	5.2	77.7^{1}	12.5	68.8	17.5
2^{b}	130.0^{1}	0.0	92.0^{2}	15.1	113.0^{1}	11.1	109.0^{1}	14.0	111.0	17.3
3^{c}	238.7^{1}	3.8	109.3^{2}	17.9	144.7^{3}	9.6	233.0^{1}	23.6	181.4	59.9
4^{b}	154.3^{1}	11.7	103.3^{2}	21.5	93.3^{2}	3.5	169.0^{1}	23.5	130.0	36.7
5^{b}	208.7^{1}	11.0	74.3^{2}	17.6	37.3^{2}	11.2	169.3^{4}	4.5	122.4	73.1
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7^{d}	37.0^{1}	0.0	25.7^{2}	2.1	39.7^{1}	0.6	72.3^{3}	4.0	43.7	18.2
8^{a}	148.3^{1}	8.7	48.3^{2}	11.7	68.0^{3}	4.4	58.7^{3}	5.0	80.8	41.9

Mean total number of individuals showed a negative correlation (decreasing water quality values) with percent imperviousness (R = -0.64). However, it was not significant at p values ≤ 0.05 (Figure 4.11).

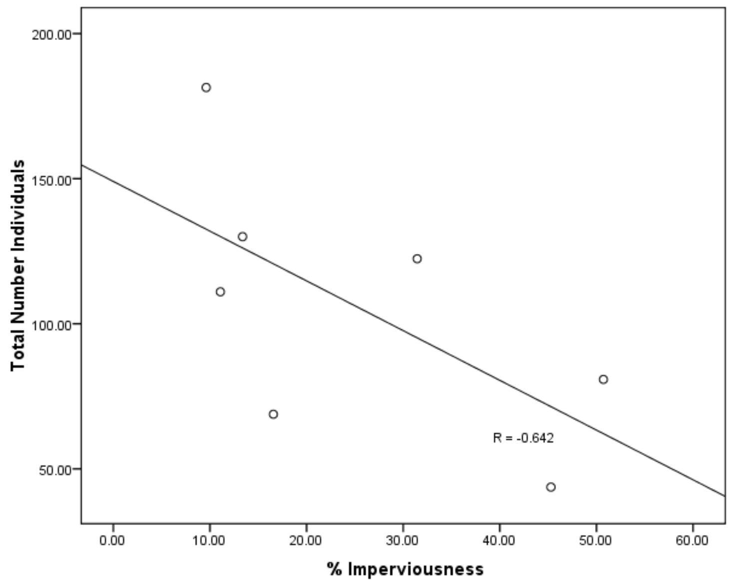

Figure 4.11 Relationship between percent imperviousness and total number of individuals

- Taxa Richness

Mean taxa richness ranged from 5.7 taxa (site 8) to 25.3 taxa (site 3) (Table 4.6). Site 3 was significantly the highest and site 8 was significantly the lowest in mean taxa richness. Sites 1 and 5 were not significantly different from each other but were different from sites 2, 4 and 7 that were also not significantly different from each others.

Spring was higher in taxa richness than other seasons in sites 2, 3, 4 and 5 while sites 1, 7 and 8 were variable.

Table 4.6 Taxa richness values in Hunnicutt creek sampled from summer, fall, winter and spring. Sites with the same letter were not different from each other. Seasons with the same number were not different from each other.

Taxa Richness										
Site ID	Summer 07		Fall 07		Winter 07		Spring 08		Average	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1^{a}	9.7^{1}	1.2	10.3^{1}	3.5	10.3^{1}	1.2	13.0^{1}	2.0	10.8	2.3
2^{b}	14.0^{1}	1.7	16.7^{2}	3.2	12.0^{1}	0.0	18.3^{2}	2.5	15.3	3.2
3^{c}	24.7^{1}	0.6	25.7^{1}	1.2	21.7^{3}	0.6	29.3^{4}	2.3	25.3	3.1
4^{d}	19.7^{1}	1.2	17.7^{1}	4.0	15.7^{1}	0.6	25.3^{2}	3.5	19.6	4.4
5^{a}	11.3^{1}	0.6	11.7^{1}	2.3	12.0^{1}	1.0	15.7^{2}	0.6	12.7	2.1
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7^{e}	10.0^{1}	0.0	7.0^{2}	0.0	7.0^{2}	0.0	8.0^{2}	0.0	8.0	1.3
8^{f}	6.0^{1}	0.0	4.7^{2}	0.6	6.0^{1}	0.0	6.0^{1}	0.0	5.7	0.7

The correlation analysis indicated that percent imperviousness was significantly correlated in a negative direction (decreasing water quality values) (R = -0.83) with taxa richness at p value $\leq$ 0.05 (Figure 4.12). Sites 2, 3 and 4 with percent imperviousness less than 15 were higher in mean taxa richness than other sites.

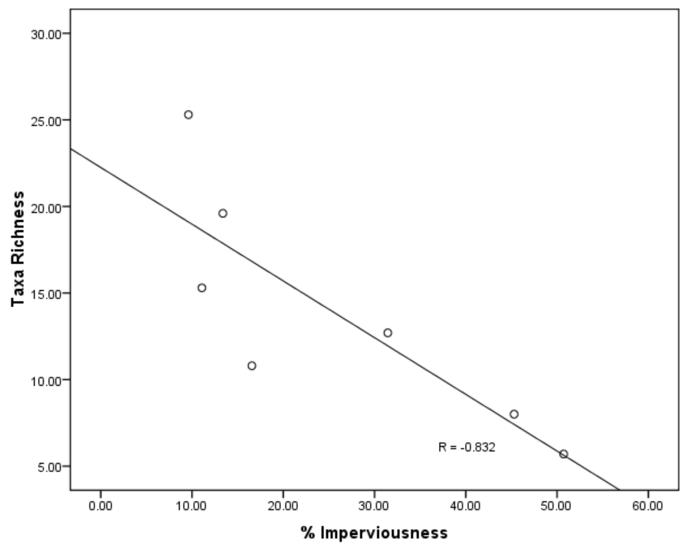

Figure 4.12 Relationship between percent imperviousness and mean taxa richness.

- **EPT Richness**

Mean EPT richness ranged from highest in site 3 (11.9 taxa) to lowest in site 8 (0.8 taxa). Sites 1, 7 and 8 were not significantly different from each other in mean EPT richness taxa. Sites 2, 4 and 5 are significantly different from all others sites (Table 4.7).

Most EPT richness values in the fall were lower than other seasons except at sites 1, 5 and 7.

Table 4.7 EPT Richness in Hunnicutt creek sampled from summer, fall, winter and spring. Sites with the same letter were not different from each other. Seasons with the same number were not different from each others at p-value ≤ 0.05

EPT Richness										
Site ID	**Summer 07**		**Fall 07**		**Winter 07**		**Spring 08**		**Average**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1[a]	3.0[1]	1.0	2.7[1]	2.1	3.3[1]	1.2	1.7[1]	0.6	2.7	1.3
2[b]	6.7[1]	0.6	4.7[2]	0.6	8.0[1]	0.0	9.0[1]	1.7	7.1	1.9
3[c]	12.0[1]	0.0	7.3[2]	0.6	12.7[1]	0.6	15.7[3]	2.1	11.9	3.3
4[d]	9.3[1]	0.6	6.7[2]	1.2	10.7[1]	0.6	13.7[1]	2.9	10.1	3.0
5[e]	4.3[1]	0.6	3.7[1]	1.5	5.7[1]	0.6	6.3[2]	0.6	5.0	1.3
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7[a]	2.0[1]	0.0	1.3[2]	0.6	1.0[2]	0.0	2.3[1]	1.2	1.7	0.6
8[a]	2.0[1]	0.0	0.0[2]	0.0	0.0[2]	0.0	1.0[1]	0.0	0.8	0.9

The correlation analysis indicated that percent imperviousness was significant and negatively correlated (decreasing water quality values) with EPT richness (R = -0.81) at p value ≤ 0.05 (Figure 4.13). First three lowest percent imperviousness sites (sites 3, 2 and 4) had the highest mean EPT richness values (11.9, 7.1 and 10.1, respectively). These three sites were located on the same tributary.

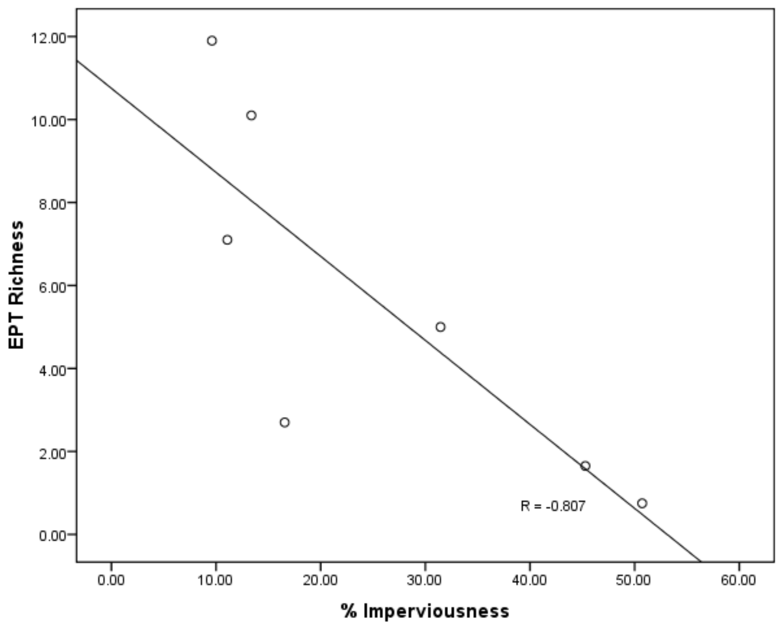

Figure 4.13 Relationship between percent imperviousness and mean EPT richness.

- **Biotic Index**

Mean biotic index scores ranged from 4.7 or excellent at site 3 to 6.8 or fair at site 8. Mean biotic indices of 2 sites (3 and 4) were considered ‘excellent’, 2 sites (2 and 5) were ‘good’ and 2 sites (1 and 7) were good-fair. Only site 8 was fair. The statistical tests for the differences between the biotic indices of sites showed the best average water quality at sites 3 and

4 and that these sites were not different from each other. Sites 2, 5 and 7 were not different and had poorer water quality. Sites 1 and 8 were different from all other sites and showed the lowest in water quality.

Summer, winter and spring show higher water quality than fall in all sites except sites 5 and 7 (Table 4.8).

Table 4.8 Biotic indices values for Hunnicutt creek sampled from summer, fall, winter and spring. Lower scores indicated better water quality. Sites with the same letter were not different from each other. Seasons with the same number were not different from each others. Biotic index value ≤ 5.19 = Excellent, 5.19-5.78 = Good, 5.79-6.48 = Good-Fair, 6.49-7.48 = Fair, >7.48 = Poor.

	Biotic Indices									
Site ID	**Summer 07**		**Fall 07**		**Winter 07**		**Spring 08**		**Average**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1[a]	5.6[1]	0.2	6.9[2]	0.3	6.0[1]	0.3	6.0[1]	0.2	6.1	0.5
2[b]	5.4[1]	0.1	6.1[2]	0.4	4.7[3]	0.4	4.8[1]	0.3	5.2	0.6
3[c]	4.7[1]	0.0	5.3[2]	0.1	4.1[3]	0.1	4.9[4]	0.1	4.7	0.5
4[c]	4.9[1]	0.1	5.6[2]	0.3	4.2[1]	0.1	4.7[1]	0.1	4.9	0.5
5[b]	4.9[1]	0.0	5.6[2]	0.4	5.5[2]	0.3	4.9[1]	0.1	5.2	0.4
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7[b]	5.9[1]	0.0	6.1[2]	0.0	6.1[2]	0.0	5.7[3]	0.1	5.9	0.2
8[d]	6.6[1]	0.1	8.0[2]	0.1	6.4[1]	0.0	6.4[1]	0.4	6.8	0.8

Mean biotic indices showed a positive correlation (decreasing water quality values) with percent imperviousness ($R = 0.75$). However, it was not significant at p values ≤ 0.05 (Figure 4.14).

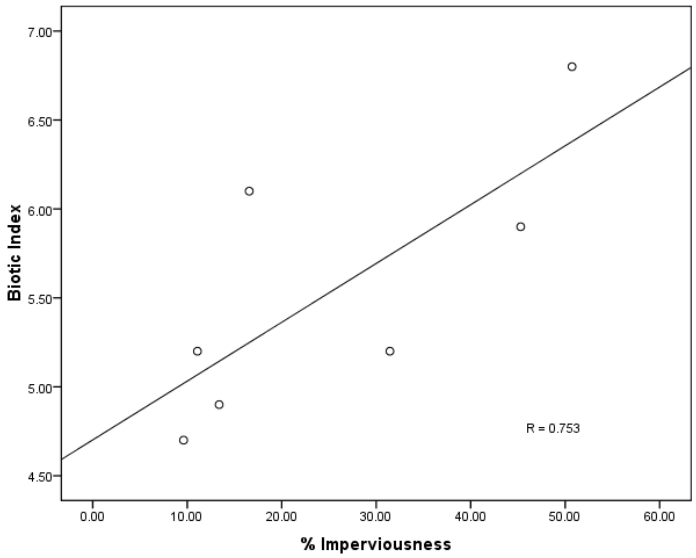

Figure 4.14 Relationship between percent imperviousness and mean biotic indices.

- **Percent Chironomidae**

Mean percent chironomidae ranged from 9.4% (site 3) to 57.4% (site 1). Sites 1 and 8 had significantly, the highest percent chironomidae while sites 1 and 3 had significantly, the lowest (Table 4.9).

The density of chironomidae was significantly higher in winter and lower in other seasons.

Table 4.9 Percent Chiromomidae in Hunnicutt creek sampled from summer, fall, winter and spring. Sites with the same letter were not different from each other. Seasons with the same number were not different from each other.

Percent Chironomidae										
Site ID	**Summer 07**		**Fall 07**		**Winter 07**		**Spring 08**		**Average**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1[a]	52.7[1]	8.5	58.3[1]	10.6	71.7[2]	3.1	47.0[1]	8.2	57.4	11.8
2[b]	36.7[1]	2.3	20.0[2]	5.0	37.7[1]	3.8	27.0[3]	2.6	30.3	8.2
3[c]	10.7[1]	0.6	5.0[2]	2.7	17.7[3]	2.5	4.3[2]	0.6	9.4	5.8
4[c]	16.7[1]	2.1	6.3[2]	1.2	24.0[3]	3.6	21.7[3]	1.5	17.2	7.4
5[d]	38.3[1]	2.9	36.0[1]	4.4	55.0[2]	6.1	27.0[3]	2.7	39.1	11.2
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7[d]	41.0[1]	0.0	33.3[2]	5.1	60.7[3]	1.2	25.0[4]	1.0	40.0	14.0
8[a]	57.3[1]	6.0	50.0[1]	8.9	61.0[1]	9.5	34.3[2]	9.3	50.7	12.9

Mean percent chironomidae showed a positive correlation (decreasing water quality values) with percent imperviousness (R = 0.57). However, it was not significant at p values ≤ 0.05 (Figure 4.15).

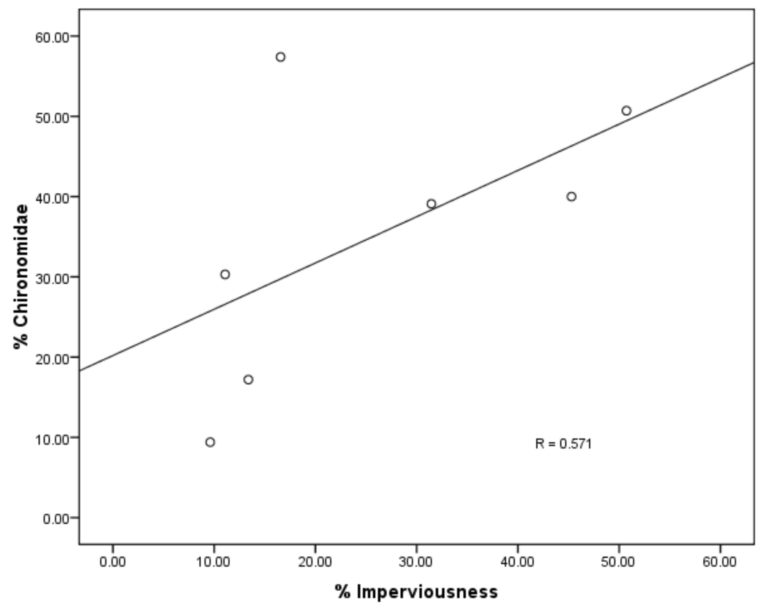

Figure 4.15 Relationship between percent imperviousness and mean percent chironomidae.

- **Percent Oligochaeta**

Mean percent oligochaeta ranged from 1.5% (site 3) to 39.1% (site 8). Site 2, 3, 4 and 5 are not significantly different in mean percent oligochaeta. Sites 1, 7 and 8 were significantly different from other sites (Table 4.10).

Fall had significantly the highest percent oligochaeta of all sites except sites 2 and 5 while other seasons were variable.

Table 4.10 Percent Oligochaeta in Hunnicutt Creek sampled from summer, fall, winter and spring. Sites with the same letter were not different from each other. Seasons with the same number were not different from each other.

Percent Oligochaeta										
Site ID	**Summer 07**		**Fall 07**		**Winter 07**		**Spring 08**		**Average**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1[a]	8.7[1]	0.6	15.7[2]	1.2	5.0[3]	1.0	12.7[4]	0.6	10.5	4.3
2[b]	3.7[1]	0.6	2.3[2]	0.6	3.3[1]	0.6	2.0[2]	1.0	2.8	0.9
3[b]	0.0[1]	0.0	3.0[2]	2.0	3.0[2]	1.0	0.0[1]	0.0	1.5	1.8
4[b]	0.7[1]	0.6	4.0[2]	3.5	1.7[1]	0.6	0.3[1]	0.6	1.7	2.1
5[b]	2.3[1]	0.6	2.0[1]	1.0	6.7[2]	3.1	1.0[1]	0.0	3.0	2.7
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7[c]	8.0[1]	0.0	27.3[2]	2.1	19.0[3]	1.7	13.7[4]	1.5	17.0	7.6
8[d]	35.0[1]	5.6	42.7[2]	9.3	30.3[1]	10.3	48.3[2]	5.7	39.1	9.9

The correlation analysis indicated that percent imperviousness had a significantly positive correlation with percent oligochaeta ($R = 0.81$) at p value ≤ 0.05 (Figure 4.16). Sites 2, 3 and 4 located in the same sub-watershed had the lowest percent oligochaeta and percent imperviousness while other sites were variable.

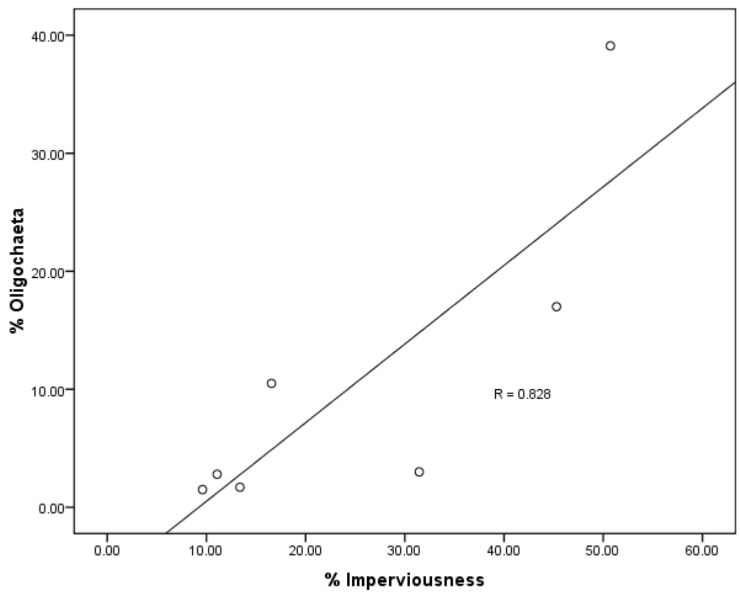

Figure 4.16 Relationship between percent imperviousness and mean percent oligochaeta.

- **Bioclassification**

Mean bioclassification scores indicated water quality of Hunnicutt Creek watershed ranged from ‘Fair’ (sites 1, 7 and 8) to ‘Good-Fair’ (sites 2, 3, 4 and 5) (Table 4.11).

Fall showed the lowest water quality in all sites. Site 3 has the highest bioclassification score in all seasons while site 8 has the lowest.

Table 4.11 Bioclassification of Hunnicutt Creek. (1 = Poor, 2 = Fair, 3 = Good-Fair, 4 = Good, and 5 = Excellent)

Site ID	**Bioclassification**					
	Summer 07	**Fall 07**	**Winter 07**	**Spring 08**	**Average**	
1	2.3	1.4	2.1	2.1	1.9	Fair
2	2.7	2	3.2	3.3	2.8	Good-Fair
3	3.5	2.7	3.5	3.8	3.4	Good-Fair
4	3.3	2.5	3.5	3.6	3.3	Good-Fair
5	3	2.3	2.7	3.2	2.8	Good-Fair
6	n/a	n/a	n/a	n/a	n/a	n/a
7	2	2	2	2.3	2.1	Fair
8	1.5	1	2	1.8	1.6	Fair

Mean bioclassification showed a negative correlation (decreasing water quality values) with percent imperviousness (R = -0.72). However, it was not significant at p values ≤ 0.05 (Figure 4.17).

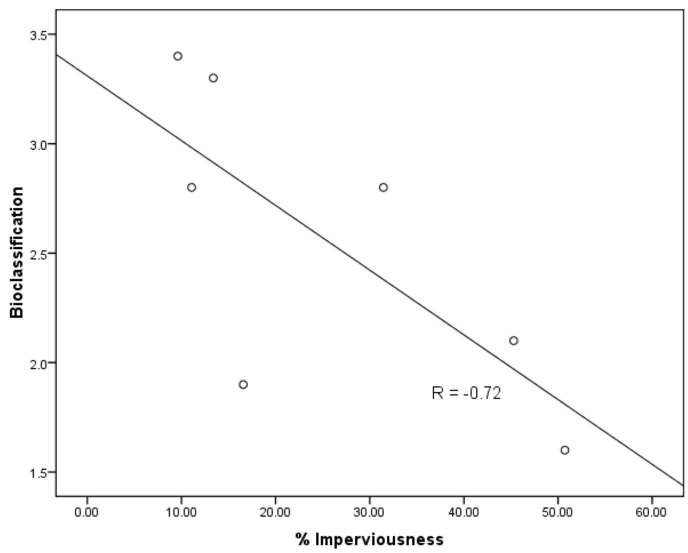

Figure 4.17 Relationship between percent imperviousness and bioclassification.

CHAPTER V

DISCUSSION

5.1 Percent imperviousness among the sub-watersheds

Hunnicutt Creek showed an impairment of water quality due to the area of impervious surfaces within the watershed. Morse et al. (2003) found the level of impervious surface below 5% was not associated with water quality impacts. Roy et al. (2003) found 15-20% urban land cover resulted in poorer water quality. In this study, percent sub-watershed imperviousness varied from 9.61% (site 3; north fork in South Carolina Botanical Garden) to 50.72% (site 8; academic zone). Sites 2, 3 and 4 which were located in the SC botanical garden branch were the three lowest in percent imperviousness (9-13%). It can be inferred that the SC botanical garden with its abundance of green spaces was helpful for preserving water quality in that sub-watershed. Sites 5, 6, and 7 had high percent imperviousness (23-45%). Almost half the area of site 7 was covered by parking lots. Site 6 which had 23.24% imperviousness was dry during this research due to a drought and no samples were collected. In the preliminary studies this site had flowing water. During this drought, site 6 had water flows that were very low. Site 1 which included all of the study area, except site 8, had only 16.56 percent imperviousness. This value may provide an incorrect view of the impact from the sub-watersheds that make up the whole of Hunnicutt Creek watershed. These data indicated that calculation of impervious surfaces conducted on small sub-watersheds provides a more realistic value for percent imperviousness that may impact the watershed as a whole.

5.2 Water quality differences among the sub-watersheds.

5.2.1 Habitat Analysis

In this study, the overall habitat scores were significantly different among sub-watersheds and can be divided into three groups. Group one had the highest in habitat scores and were composed of sites 2, 3 and 4. Group two which had moderate habitat scores was composed of sites 5 and 6. Group three had the lowest habitat score and was composed of sites 1, 7 and 8. Group 1, sites 2, 3 and 4 also had the lowest imperviousness. Group 3, sites 7 and 8 had the highest imperviousness.

5.2.2 Physical and Chemical Analysis

The results indicated that water quality parameters may be used to identify different degrees of pollution and disturbance in the study sites. The values of each water quality parameters were significantly different between sites except temperature and phosphate. All water quality parameters sampled from each sites were within water quality standards except phosphate.

- Temperature

Seasonal variations in stream temperature may be caused by changing air temperature, solar angle, meteorological events, and a number of physical aspects related to the stream and watershed including stream origin, velocity, vegetation types and coverage, stream configuration, land-use, and percentage of impervious area (Center for Environmental Quality, 2009). The mean temperatures among sites in Hunnicutt Creek during the study time were not significantly different in statistical test. However, the temperature of each site was different by at least 7 ºC when sampled from different seasons.

- pH

pH of water may have been affected by several factors such as the dumping of chemical into water, the amount of acid precipitation, bedrock and soil composition through which the water moves (Center for Environmental Quality, 2009). However, pH values ranged from 6.0-8.1 were within acceptable limits of quality standards for freshwater (6.0-8.5) (SCDHEC, 2004) indicating that the water quality in Hunnicutt Creek was not impaired.

- Dissolved Oxygen

Dissolved oxygen from each site ranged from 4.7-9.7 and was within acceptable limits because the daily average were not less than 5.0 mg/L and did not have a low of 4.0 mg/l (SCDHEC, 2004).

- Conductivity

Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate (USEPA, 2009). Conductivity of all sites ranged from 53-134 µS was lower than the water quality standard which is ≤800 µS/cm (KYwater, 2009). Although the conductivity from all sites did not exceed the standard, it was interesting that site 8 had the highest value of conductivity for all seasons. Site 8 which received water from academic zone may be slightly affected by the pollution sources.

- Phosphate

Phosphate may enter waterways from human and animal waste, phosphorus rich bedrock, laundry, cleaning, industrial effluents and fertilizer runoff. From this study, phosphate concentrations sampled from all sites ranged from 0-0.87 ppm. Although the mean phosphate among sampled sites was not significantly different, all sites tended to be slightly contaminated by phosphate because the natural levels of dissolved phosphate are around 0.01 ppm for PO_4^{-3} (Allan, 2006).

- Nitrate-nitrogen

Nitrate in water might come from fertilizer runoff, leaky cesspool, sewage treatment plants, manure runoff, and car exhausts (Center for Environmental Quality, 2009). Nitrate-nitrogen concentration sampled from sites ranged from 0.08-1.08 ppm and did not exceed the standard nitrate levels in drinking water (10 ppm) (Wisconsin DNR, 2009).

5.2.3 Biological Analysis

5.2.3.1 Fecal Coliform

The fecal coliform standards for freshwaters established by SCDHEC (2004) are that they should not exceed a geometric mean of 200/100 ml, based on five consecutive samples during 30 day period; nor shall more than 10% of the total samples during any 30 day period exceed 400/100 ml. This research showed that all samples collected in summer and fall 2007exceeded 200 CFUs/100 ml. Four of seven in winter of 2007 and spring of 2008 samples exceed 200 CFUs/100ml.

High amount of sediments are often related to high concentration of fecal coliform (Jolly 2005). Fecal coliform can attach to sediment particles and are much more abundant in sediment particles than in water. In this study, mean CFUs of bottom sediments were at least 200 times higher than mean CFUs in surface water. These results agree with the studying of Jolly (2005) which found means CFUs of bottom sediments were 10-10,000 times higher than mean CFUs for surface water.

5.2.3.2 Macroinvertebrate

Macroinvertebrate indicators for each site were somewhat variable but several trends were apparent. Biotic index, taxa richness and EPT richness were highest at site 2, 3 and site 4. In addition, % Oligochaeta and % Chironomidae parameters, indicators of poor water quality, were lowest in these sites. These results indicated that sites 2, 3 and 4 which were located in SC Botanical Garden had the highest biotic integrity of the whole Hunnicutt Creek watershed. Site 8 which received storm water from campus area had the poorest water quality and did not have any intolerant taxa. Sites 1, 5 and 7 were significantly different from each others in some metrics. Biotic index, Taxa richness and EPT richness were used as indicators of the water quality in Hunnicutt Creek because these metrics can show contrast between impacted and non-impacted sites. Wallace et al. (1996) reported that EPT taxa richness is the most reliable measurement used by biologist and this index is very sensitive to changes in water quality and less variable. There were some significant data related to season. Macroinvertebrate densities were highest during spring, winter and summer, indicating these periods may be more favorable for aquatic insect production than fall.

5.3 Relationship between the sub-watershed percent imperviousness and water quality parameters and macroinvertebrate community metrics.

5.3.1 Relationship between percent imperviousness and habitat score.

In this study, percent imperviousness showed a significantly negative correlation with habitat scores at p-values ≤ 0.05 ($R = -0.87$). Imperviousness and the biological integrity in streams are believed to be closely linked and altered habitat structure may be major stress on streams (Karr et al., 1986). It may be useful to consider that land uses in the riparian area were considered equal or more influential relative to land use than elsewhere in the watershed, although riparian area consisted of only a small portion of entire watershed area (Wang and Kanehl, 2003). It may be useful in future studies to evaluate the integrity of riparian zones relative to imperviousness of the watershed.

5.3.2 Relationship between percent imperviousness and water quality parameters.

5.3.2.1 Physical and Chemical Parameters

- Temperature

In this study, percent imperviousness had a positive correlation with mean temperature ($R=0.47$), however, it was not significant at p-values ≤ 0.05. Impervious surface can be a cause of an increasing of temperature. Hot pavement and rooftop surfaces may transfer their excess heat to stormwater, which then drains into storm sewers and raises water temperatures as it is released into streams (USEPA, 2009). It may be assumed that stream water temperature influenced by impervious surface heating would increase and decrease quickly in response to rain events. Ground water temperatures should be lower than impervious surface runoff and should dominate water temperatures not associated with storm flows. In this studying the time of temperature measurements since last rain storm was not recorded.

- pH

Percent imperviousness had a negative correlation with pH (R= -0.69) but not significantly at p-values ≤ 0.05. This result disagreed with that of Conway (2007) who found percent impervious surface in drainage is strongly correlated with pH. This may be due to the span of time from last rain event and instream sampling.

- Dissolved Oxygen

Percent imperviousness had a significant negative correlation with dissolved oxygen (R= -0.87) at p-values ≤ 0.05. Although dissolved oxygen levels were never below acceptable limits when measured, the data suggests imperviousness may have some impact on dissolved oxygen levels. Site 1 located at the downstream of the golf course had the highest mean dissolved oxygen. The stream has no riparian cover though the golf course and the increase in dissolved oxygen may be the result of an increase in photosynthesis within the channel.

- Conductivity

Percent imperviousness was significantly correlated with mean conductivity (R=0.78) at p-values ≤ 0.05. This result disagreed with the studying of Department of Ecology, State of Washington (2009) which found that impervious surface levels appeared to have little effect on conductivity levels for either the base-flow or storm-flow.

- Phosphate

Percent imperviousness was not correlated with percent mean phosphate at p-values ≤ 0.05. Spahr and Wynn (1997) found that sites within the agricultural areas generally had higher concentrations of nitrogen and phosphorus than urbanized areas. It was interesting that site 3, which had the lowest percent imperviousness and located in the SC botanical garden, had a relatively high mean phosphate value. Site 1 also had low imperviousness and was located directly downstream of the golf course had the highest mean phosphate level (0.24 mg/l). The elevated levels at both 1 and 3 may be an indication of fertilizer runoff.

- Nitrate-N

Percent imperviousness was positively correlated with nitrate (R=0.63) but not significantly at p-values ≤ 0.05.

5.3.2.2 Biological Parameters

1) Fecal Coliform bacteria

Percent imperviousness showed a significant positive correlation with fecal coliform bacteria both in water and bottom sediment at p-values ≤ 0.05 (R = 0.89 and 0.85, respectively). There are a lot of factors affected the fecal coliform bacteria such as waste water and septic system effluent, animal waste, temperature, sediment load and nutrients. Schoonover et al. (2005) found fecal coliform bacteria in streams with more than 5 percent imperviousness often exceeded the US EPA’s standard for recreation waters. The source of fecal coliform in Hunnicutt Creek is unknown. Because most readings exceed state standards, more research including source tracking needs to be conducted and the source eliminated.

2) Macroinvertebrates

In general, percent imperviousness was an effective representative variable for measuring the effects of urbanization on macroinvertebrates. Most macroinvertebrate matrices showed a correlation with percent imperviousness.

Total number of individuals showed a negative correlations with percent imperviousness ($R = -0.64$) but not significant at p-values ≤ 0.05. This study agrees with Gray (2004) and Roy et al. (2003) who found negative correlations between urban land cover and total density.

Taxa richness showed significant correlation with percent imperviousness in a negative direction ($R=-0.83$) at p-values ≤ 0.05. The three sites with lowest percent imperviousness (sites 2, 3 and 4) had the highest mean taxa richness. This study agreed with Roy et al. (2003) ,Wang and Kanehl (2003) and Sponseller et al. (2001) who also found negative linear relationships between taxa richness and percent urban land cover and percent imperviousness.

Percent imperviousness was negatively correlated with EPT richness ($R = -0.81$) at p-values ≤ 0.05. Roy et al. (2003), Wang and Kanehl (2003) and Stepenuck et al. (2002) also found watershed imperviousness was negatively associated EPT richness.

Percent imperviousness had a positive correlation with the biotic index ($R = 0.75$) but the relationship was not significant at p-values ≤ 0.05. Sites 3 and 4 which had the lowest percent imperviousness (9.61 and 13.38, respectively) also had the lowest mean biotic indices. Likewise, site 8 which had the highest percent imperviousness (50.72) also had the highest mean biotic index. Sites 1, 5 and 7 were variable. This result agreed with Stepenuck et al.

(2002) who found strong relationship between biotic index and percent imperviousness. Roy et al. (2003) also found the relationships between NCBI and urban land cover to indicate degraded water at 15-20% imperviousness.

CHAPTER VI

CONCLUSION

The average percent imperviousness in the Hunnicutt Creek watershed was 21% which can be classified as an urbanized area. However, the percent imperviousness was different among sub-watersheds. The water quality in the study area tended to be most impacted in watersheds with high imperviousness. Sites within the headwaters on McMillan road (6 and 7) seemed to be severely affected by the parking lots. Also site 8, the academic zone had high imperviousness and water quality degradation.

Habitat score, dissolved oxygen, taxa richness and EPT richness showed significant negative correlation with percent imperviousness. Conductivity, fecal coliform (surface water and bottom sediment) and oligochaeta showed significant positive correlation with percent imperviousness at p-value ≤ 0.05 (Table 6.1).

Further research will be needed to determine sources of fecal coliform pollution. Additional research is needed specifically at site 8 that had the worse water quality. In addition, research may be directed to determine the relationship between physical/chemical parameter and macroinvertebrate metrics. Also, it would be useful to determine relationships between particular types of land uses, riparian zone quality and water quality parameters.

Table 6.1 Conclusion of relationships between percent imperviousness and water quality parameters. (R with * means parameter showed significant correlation with percent imperviousness)

Parameters	**R**
Habitat Score	-0.87*
Temperature	0.47
pH	-0.69
Dissolved oxygen	-0.87*
Conductivity	0.78*
Phosphate	-0.27
Nitrate	0.63
Fecal coliform in surface water	0.89*
Fecal coliform in bottom sediment	0.85*
Total number of individuals	-0.64
Taxa richness	-0.83*
EPT richness	-0.81*
Biotic index	0.75
Chironomidae	0.57
Oligochaeta	0.82*
Bioclassification	-0.72

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APPENDIX

Macroinvertebrate identification

Summer 2007: Replication 1

			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta			7	5	1	1	5		3	57
Class Insecta										
Order Coleoptera										
	Dryopidae									
		Helichus sp.			1					
	Elmidae									
		Ancyronyx variegata				1			3	
		Macronychus glabratus	1		3	3				
		Stenelmis sp.	1	2	15	9	2			
Order Collembola					1				1	
Order Diptera										
	Chironimidae		48	49	27	25	87		15	92
	Culicidae									
		Culex sp.		1						
	Dixidae									
		Dixa sp.			2	3	6			
	Ephydridae				2					
		Notiphila sp.					1			
	Simuliidae									
		Simulium sp.	9	7	3	4	85		4	2
	Tipulidae									
		Tipula sp.	3	2	9	6	1		3	5
Order Ephemeroptera										
		Baetis sp.	7	8	5	24	5			
	Heptageniidae									
		Stenonema modestum		5	13	9				
Order Hemiptera										
	Veliidae									
		Rhagovelia sp.	1	1	1	2			1	
Order Odonata										
	Aeshnidae				2	1				
	Calopterygidae									
		Calopteryx sp.							2	
Order Plecoptera										
	Perlidae				18					

Summer 2007: Replication 1 (Cont'd)

			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
		Eccoptura xanthenes			2	2				
		Perlesta sp.		1	75	12				
Order Trichoptera										
	Hydropsychidae									
		Ceratopsyche sparna			5		1			
		Cheumatopsyche sp.	5	46	28	53	21		4	1
		Diplectrona modesta			1				1	
		Hydropsyche sp.		2	13	4				
		Hydropsyche betteni					1			1
	Lepidostomatidae									
		Lepidostoma sp.			3	2				
	Philopotamidae									
		Chimarra sp.			6	1				
	Uenoidae									
		Neophylax sp.		1	1	1				

Summer 2007: Replication 2

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	9	4			5		3	42
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.		1	2	2				
Elmidae								
Ancyronyx variegata		1	1	1			3	
Macronychus glabratus			1	2				
Stenelmis sp.		3	15	2	2			
Order Collembola			1				1	
Order Diptera								
Chironimidae	42	44	24	27	69		15	92
Culicidae								
Culex sp.	1		1					
Dixidae								
Dixa sp.		1	4	2	4			
Ephydridae			2					
Notiphila sp.					1			
Simuliidae								
Simulium sp.	27	7	8	6	85		4	2
Tipulidae								
Tipula sp.	4	1	9	1	1		3	5
Order Ephemeroptera								
Baetidae								
Baetis sp.	7	8	5	24	5			
Heptageniidae								
Stenonema modestum		5	13	7				
Order Hemiptera								
Veliidae								
Rhagovelia sp.	1	1	1	2			1	
Order Odonata								
Aeshnidae			2	1				
Calopterygidae								
Calopteryx sp.							2	
Order Plecoptera								
Perlidae			18					
Eccoptura xanthenes			1	1				
Perlesta sp.		1	82	1				
Order Trichoptera								
Hydropsychidae								

Summer 2007: Replication 2 (Cont'd)

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
	Ceratopsyche sparna			5		1			
	Cheumatopsyche sp.	2	46	28	53	21		4	3
	Diplectrona modesta			1				1	
	Hydropsyche sp.		5	13	4				
	Hydropsyche betteni	4				1			2
Lepidostomatidae									
	Lepidostoma sp.			4	2				
Philopotamidae									
	Chimarra sp.		1	6	1	1			
Uenoidae									
	Neophylax sp.		1	3	2				

Summer 2007: Replication 3

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	7	5	1	1	5		3	57
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.			3	3				
Elmidae								
Ancyronyx variegata			1	2			3	
Macronychus glabratus			1	2				
Stenelmis sp.	3	2	15	4	2			
Order Collembola			1				1	
Order Diptera								
Chironimidae	48	49	27	25	87		15	72
Culicidae								
Culex sp.	1							
Dixidae								
Dixa sp.			3	5	6			
Ephydridae			2					
Notiphila sp.					1			
Simuliidae								
Simulium sp.	9	7	1	5	85		4	2
Tipula sp.	5	2	9	1	1		3	5
Order Ephemeroptera								
Baetidae								
Baetis sp.	7	8	5	24	5			
Heptageniidae								
Stenonema modestum	1	5	13	7				
Order Hemiptera								
Veliidae								
Rhagovelia sp.	1	1	1	2			1	
Order Odonata								
Aeshnidae			2	1				
Calopterygidae								
Calopteryx sp.							2	
Order Plecoptera								
Perlidae			18					
Eccoptura xanthenes			1	1				
Perlesta sp.		1	62	12				
Order Trichoptera								
Hydropsychidae								
Ceratopsyche sparna			5	1	1			
Cheumatopsyche sp.	1	46	28	53	21		4	3

Summer 2007: Replication 3 (Cont'd)

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
	Diplectrona modesta			1				1	
	Hydropsyche sp.		2	13	4				
	Hydropsyche betteni	2				1			2
Lepidostomatidae									
	Lepidostoma sp.			3	2				
Philopotamidae									
	Chimarra sp.		1	6	2				
Uenoidae									
	Neophylax sp.		1	1	2				

Fall 2007: Replication 1

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	7	2	7	7	1		7	17
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.		8	2	1				
Dytiscidae								
Ilybius sp.		1	1					
Elmidae								
Ancyronyx variegata				5				
Macronychus glabratus		14		18				
Promoresia sp.			1					
Stenelmis sp.		2	11	8				
Psephenidae								
Ectopria sp.			1	1				
Ptilodactylidae								
Anchytarsus bicolor			1					
Order Collembola			4	1				
Order Diptera								
Chironimidae	22	14	3	6	28		7	15
Culicidae								
Anopheles sp.			1					
Dixidae								
Dixa sp.			1					
Simuliidae								
Simulium sp.			9	2	9		3	
Tabanidae								
Chrysops sp.			1					
Tipulidae								
Antocha sp.			1					
Dicranota sp.					1			
Erioptera sp.					1			
Tipula sp.	1	1	4	2	1		1	
Order Ephemeroptera								
Baetidae								
Baetis sp.	2	10	2	4	9		2	
Procloeon sp.	1							

Fall 2007: Replication 1 (Cont'd)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Pseudocloeon sp.	1	1	3		2			
Heptageniidae								
Stenonema carlsoni		2						
Stenonema exiguum								
Stenonema modestum	2	6	13	2	1			
Order Hemiptera								
Veliidae								
Microvelia sp.		1					1	
Rhagovelia obese	1	3	1	4	1			
Order Odonata								
Aeshnidae								
Boyeria vinosa	1	1	1	1				
Calopterygidae								
Calopteryx sp.	3	4	1	2	5			1
Calopteryx maculate	1							
Coenagrionidae								
Argia sp.								1
Cordulegastridae								
Cordulegaster sp.		1	1					
Gomphidae		2						
Dromogomphus sp.	3							
Progomphus obscures	1	1						
Stylogomphus albistylus				1				
Libellulidae								1
Order Plecoptera								
Perlidae								
Eccoptura xanthenes			17	1				
Hydropsychidae								
Ceratopsyche sparna			2					
Cheumatopsyche sp.	1	20	27	6	8			
Diplectrona modesta			2	1	2			
Hydropsyche betteni			12	8			3	
Leptoceridae								
Triaenodes sp.				3				
Polycentropodidae								
Polycentropus sp.				1				

Fall 2007: Replication 2

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	10	2	3	3	2		7	17
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.			2	1				
Dytiscidae								
Ilybius sp.		1	1					
Elmidae								
Macronychus glabratus		1		19				
Promoresia sp.			1					
Stenelmis sp.		8	15	15				
Psephenidae								
Ectopria sp.			1					
Ptilodactylidae								
Anchytarsus bicolor			1					
Order Collembola			7	3				
Order Diptera								
Chironimidae	35	19	7	6	20		11	32
Culicidae								
Anopheles sp.			1					
Dixidae								
Dixa sp.			1					
Simuliidae								
Simulium sp.			6	11	9		3	
Tabanidae								
Chrysops sp.			1					
Tipulidae								
Antocha sp.			1					
Dicranota sp.					1			
Erioptera sp.					1			
Tipula sp.	1	1	1	1	1		1	

Fall 2007: Replication 2 (Cont'd)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Order Ephemeroptera								
Baetidae								
Baetis sp.	2	8	2	7	9		2	
Pseudocloeon sp.			3					
Heptageniidae								
Stenonema carlsoni		2						
Stenonema modestum		6		9				
Veliidae								
Microvelia sp.							1	
Rhagovelia obesa	1	1		1				
Order Odonata								
Aeshnidae								
Boyeria vinosa			1					
Calopterygidae								
Calopteryx sp.	3	10	1	6	6			
Calopteryx maculata	1							
Coenagrionidae								
Argia sp.								3
Cordulegastridae								
Cordulegaster sp.			1					
Gomphidae		2						
Dromogomphus sp.	3							
Progomphus obscurus	1							
Stylogomphus albistylus				1				
Libellulidae								1
Order Plecoptera								
Perlidae								
Eccoptura xanthenes			6					
Order Trichoptera								
Hydropsychidae								
Ceratopsyche sparna			2					
Cheumatopsyche sp.	1	15	25	27	11			
Diplectrona modesta			1	1				
Hydropsyche betteni			9	15			3	
Polycentropodidae								
Polycentropus sp.				1				

Fall 2007: Replication 3

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	6	2	1	2	2		7	27
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.		2	1	1				
Dytiscidae								
Ilybius sp.		1	1					
Elmidae								
Ancyronyx variegata		2						
Macronychus glabratus		4		6				
Promoresia sp.			1					
Stenelmis sp.		14	8	6	9			
Psephenidae								
Ectopria sp.			1					
Ptilodactylidae								
Anchytarsus bicolor			1					
Order Collembola			1	1				
Order Diptera								
Chironimidae	28	21	6	7	32		8	27
Culicidae								
Anopheles sp.			1					
Dixidae								
Dixa sp.			1					
Simuliidae								
Simulium sp.			5	9	9		3	
Tabanidae								
Chrysops sp.			1					
Tipulidae								
Antocha sp.			1					
Dicranota sp.					1			
Erioptera sp.					1			
Tipula sp.	2	1	1		1		1	
Order Ephemeroptera								
Baetidae								
Baetis sp.		11	5	4	9		2	
Pseudocloeon sp.			3					
Heptageniidae								
Stenonema carlsoni		2						
Stenonema modestum	2	2		4	4			

Fall 2007: Replication 3 (Cont'd)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Order Hemiptera								
Veliidae								
Microvelia sp.							1	
Rhagovelia obesa	1	7			2			
Order Odonata								
Aeshnidae								
Boyeria vinosa		2	1					
Calopterygidae								
Calopteryx sp.	1	12	1	4	4			1
Calopteryx maculata	1							
Coenagrionidae								
Argia sp.								1
Cordulegastridae								
Cordulegaster sp.		1	1					
Gomphidae		5						
Libellulidae								1
Order Plecoptera								
Perlidae								
Eccoptura xanthenes			15					
Order Trichoptera								
Hydropsychidae								
Ceratopsyche sparna			3	3				
Cheumatopsyche sp.		12	27	21	12			
Diplectrona modesta			1	1				
Hydropsyche betteni		5	10	29	8		3	

Winter 2007: Replication 1

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	4	5	6	2	2		7	12
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus fastigiatus					2			
Dytiscidae								
Agabus sp.			1					
Neoporus sp.							2	
Elmidae								
Macronychus glabratus		1	3	1				
Stenelmis sp.			6	2	2		1	
Order Collembola	1		6					2
Order Diptera								
Chironimidae	48	52	28	26	24		24	45
Dixidae								
Dixa sp.	2							
Empididae								
Chelifera sp.	1							
Simuliidae								
Simulium sp.			7	14	4		2	1
Tipula sp.	2	2	7		2		2	2
Order Ephemeroptera								
Baetidae								
Baetis sp.	2	1	1	2				
Pseudocloeon sp.					2			
Ephemerellidae								
Ephemerella sp.		11	13	11				
Ephemerella invaria		2						
Heptageniidae								
Stenonema modestum		15	14	2	1			
Order Odonata								
Calopterygidae								
Calopteryx sp.	2				1			1
Cordulegastridae								
Cordulegaster sp.			1					
Order Plecoptera								
Paracapnia angulata			2					
Perlidae								
Eccoptura xanthenes			1					
Perlodidae								

Winter 2007: Replication 1 (Cont'd)

			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
		Clioperla clio			19	17				
		Isoperla sp.			8	3				
Order Trichoptera										
	Hydropsychidae									
		Cheumatopsyche sp.	2	27	7	6	3			
		Diplectrona modesta			1	1				
		Hydropsyche sp.					1			
		Hydropsyche betteni		1		3	4		2	
	Leptoceridae									
		Triaenodes ignitus			1					
	Limnephilidae									
		Pycnopsyche sp.				1				
	Philopotamidae									
		Chimarra sp.		3	2		2			
	Uenoidae									
		Neophylax sp.		3	21	2				

Winter 2007: Replication 2

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	2	3	4	2	3		8	23
Class Insecta								
Order Coleoptera								
Dytiscidae								
Agabus sp.			1					
Neoporus sp.							2	
Elmidae								
Macronychus glabratus		1	4	2				
Stenelmis sp.			5	1			1	
Order Collembola	1		3					2
Order Diptera								
Chironimidae	39	36	28	19	17		24	42
Dixidae								
Dixa sp.	1							
Empididae								
Chelifera sp.	1							
Simuliidae								
Simulium sp.			11	10	1		2	1
Tipulidae								
Tipula sp.	1	2	4		1		1	1
Order Ephemeroptera								
Baetidae								
Baetis sp.	1	1	2	1				
Pseudocloeon sp.					1			
Ephemerellidae								
Ephemerella sp.		8	11	7				
Ephemerella invaria		1						
Heptageniidae								
Stenonema exiguum	2		2	1				
Stenonema modestum	4	11	3	2	1			
Order Odonata								
Aeshnidae								
Calopterygidae								
Calopteryx sp.	1				1			1
Cordulegastridae								
Cordulegaster sp.			1					
Order Plecoptera								
Capniidae								
Paracapnia angulata			1					
Perlidae								

Winter 2007: Replication 2 (Cont'd)

			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
		Eccoptura xanthenes			1					
	Perlodidae									
		Clioperla clio			23	18				
		Isoperla sp.			6	3				
Order Trichoptera										
	Hydropsychidae									
		Cheumatopsyche sp.	2	35	12	8	1			
		Diplectrona modesta			1	1				
		Hydropsyche sp.					1			
		Hydropsyche betteni		1		7	1		1	
	Leptoceridae									
		Triaenodes ignitus			1					
	Limnephilidae									
		Pycnopsyche sp.				1				
	Philopotamidae									
		Chimarra sp.		1	1		1			
	Uenoidae									
		Neophylax sp.		1	18	7				

Winter 2007: Replication 3

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	3	4	3	1	2		7	28
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus fastigiatus					1			
Dytiscidae								
Agabus sp.			1					
Neoporus sp.							3	
Elmidae								
Macronychus glabratus		2	5	1				
Stenelmis sp.			6	2	1		1	
Order Collembola	1		2					2
Order Diptera								
Chironimidae	44	40	20	22	19		24	37
Dixidae								
Dixa sp.	2							
Empididae								
Chelifera sp.	1							
Simuliidae								
Simulium sp.			9	13	3		2	1
Tipulidae								
Tipula sp.	2	1	5		1		2	2
Order Ephemeroptera								
Baetidae								
Baetis sp.	1	1	2	1				
Pseudocloeon sp.					1			
Ephemerellidae								
Ephemerella sp.		10	12	11				
Ephemerella invaria		2						
Heptageniidae								
Stenonema exiguum	1		1	1				
Stenonema modestum	5	14	4	3				
Order Hemiptera								
Order Odonata								
Calopterygidae								
Calopteryx sp.	1				1			1
Cordulegastridae								

Winter 2007: Replication 3 (Cont'd)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Cordulegaster sp.			2					
Order Plecoptera								
Capniidae								
Paracapnia angulata			1					
Perlidae								
Eccoptura xanthenes			2					
Perlodidae								
Clioperla clio			25	24				
Isoperla sp.			8	3				
Order Trichoptera								
Hydropsychidae								
Cheumatopsyche sp.	3	35	4	8	1			
Diplectrona modesta			1	1				
Hydropsyche sp.					1			
Hydropsyche betteni		2		4	1		1	
Leptoceridae								
Triaenodes ignitus			1					
Limnephilidae								
Pycnopsyche sp.				1				
Philopotamidae								
Chimarra sp.		2	1		1			
Uenoidae								
Neophylax sp.		2	21	1				

Spring 2008: Replication 1

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	11	2			1		11	31
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.			2	3	4			
Dytiscidae								
Neoporus sp.					2			
Elmidae								
Macronychus glabratus	1		3					
Stenelmis sp.	1	2	15	8	2			
Order Collembola		1	1					
Order Diptera								
Chironimidae	35	30	11	38	49		19	16
Culicidae								
Culex sp.	2							
Dixidae								
Dixa sp.		1	4	3	2			
Simuliidae								
Simulium sp.	18	10	14	4	82		15	3
Tipulidae								
Antocha sp.	1	1	2	1				
Tipula sp.	3	2	3	3	1		6	2
Order Ephemeroptera								
Baetidae								
Baetis sp.	1	8	5	24	1			
Ephemerellidae								
Ephemerella sp.		1	1	3				
Eurylophella sp.			2	1				
Heptageniidae								
Stenonema exiguum		1	1	2				
Stenonema modestum		5	13	4				
Order Hemiptera								
Veliidae								
Rhagovelia sp.	1	2	3	4				
Order Odonata								
Aeshnidae								
Boyeria vinosa	2	1	1	1	1			
Calopterygidae								
Calopteryx sp.	5		1	1	2		5	3
Calopteryx maculata	3		1	1				
Gomphidae								

Spring 2008: Replication 1 (Cont'd)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Progomphus obscurus	1							
Stylogomphus albistylus			1	1				
Order Plecoptera								
Perlidae			17	7				
Eccoptura xanthenes			3					
Perlesta sp.		1	75	12	1			
Perlodidae								
Isoperla sp.			3	1				
Order Trichoptera								
Hydropsychidae								
Ceratopsyche sparna			5	1	3			
Cheumatopsyche sp.	7	42	28	49	21		11	3
Diplectrona modesta			7	1			1	
Hydropsyche betteni			15	7	1		8	
Lepidostomatidae								
Lepidostoma sp.		1	5	2				
Leptoceridae								
Triaenodes ignitus		1	3	3				
Limnephilidae								
Pycnopsyche sp.		1	2	1	1			
Philopotamidae								
Chimarra sp.		1	5	2				
Uenoidae								
Neophylax sp.		1	7	4				

Spring 2008: Replication 2

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	9	3	1	1	1		9	27
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.			2	2	1			
Dytiscidae								
Neoporus sp.			1	1	1			
Elmidae								
Macronychus glabratus		1	1	2				
Stenelmis sp.		3	15	7	2			
Order Collembola		1	1					
Order Diptera								
Chironimidae	35	30	11	38	49		19	16
Culicidae								
Culex sp.	2							
Dixidae								
Dixa sp.		1	4	2	2			
Simuliidae								
Simulium sp.	8	12	7	2	82		14	3
Tipulidae								
Antocha sp.	1	1	1	3				
Tipula sp.	3	2	3	7	1		6	2
Order Ephemeroptera								
Baetidae								
Baetis sp.	1	8	5	24	1			
Ephemerellidae								
Ephemerella sp.		3	4	3				
Eurylophella sp.				1				
Heptageniidae								
Stenonema exiguum				4				
Stenonema modestum		6	15	2				
Order Hemiptera								
Veliidae								
Rhagovelia sp.	1	1	1	4				

Spring 2008: Replication 2 (Cont’d)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Order Odonata								
Aeshnidae								
Boyeria vinosa	1		1	1				
Calopterygidae								
Calopteryx sp.	2		1		2		5	3
Calopteryx maculata	2							
Gomphidae								
Progomphus obscurus	1							
Stylogomphus albistylus				1				
Order Plecoptera								
Perlidae			17	2				
Eccoptura xanthenes			1					
Perlesta sp.		1	68		1			
Perlodidae								
Isoperla sp.				1				
Order Trichoptera								
Hydropsychidae								
Ceratopsyche sparna			5		3			
Cheumatopsyche sp.	6	42	28	49	21		11	3
Diplectrona modesta			1				1	
Hydropsyche betteni			13	5	1		8	
Lepidostomatidae								
Lepidostoma sp.		1	3	3				
Leptoceridae								
Triaenodes ignitus		1						
Limnephilidae								
Pycnopsyche sp.			1		1			
Philopotamidae								
Chimarra sp.			5	2				
Uenoidae								
Neophylax sp.		2	4	3				

Spring 2008: Replication 3

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Class Oligochaeta	9	1	1		1		10	27
Class Insecta								
Order Coleoptera								
Dryopidae								
Helichus sp.			2	2	1			
Dytiscidae								
Neoporus sp.					1			
Elmidae								
Macronychus glabratus	2		1					
Stenelmis sp.		1	12	1	2			
Order Collembola		2	2	1				
Order Diptera								
Chironimidae	37	28	8	34	40		16	29
Culicidae								
Culex sp.	1							
Dixidae								
Dixa sp.			2	2	2			
Simuliidae								
Simulium sp.	9	4	2	2	82		14	2
Tipulidae								
Antocha sp.			1					
Tipula sp.		1	1	1	1		6	2
Order Ephemeroptera								
Baetidae								
Baetis sp.		8	5	24	1			
Ephemerellidae								
Ephemerella sp.			7	5				
Heptageniidae								
Stenonema exiguum				3				
Stenonema modestum		2	13	4				
Order Hemiptera								
Veliidae								
Rhagovelia sp.	1	1	1	4				
Order Odonata								
Aeshnidae								
Boyeria vinosa	1	1	1	1				
Calopterygidae								

Spring 2008: Replication 3 (Cont'd)

			Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
		Calopteryx sp.	2		1		2		5	3
		Calopteryx maculata	1							
	Gomphidae									
		Progomphus obscurus	1							
		Stylogomphus albistylus				1				
Order Plecoptera										
	Perlidae				19	2				
		Eccoptura xanthenes			1					
		Perlesta sp.		2	75		1			
	Perlodidae									
		Isoperla sp.				1				
Order Trichoptera										
	Hydropsychidae									
		Ceratopsyche sparna			4		6			
		Cheumatopsyche sp.	5	38	26	45	22		9	1
		Diplectrona modesta			1				1	
		Hydropsyche betteni			12	5	1		7	
	Lepidostomatidae									
		Lepidostoma sp.		1	3	2	1			
	Leptoceridae									
		Triaenodes ignitus		1	1					
	Limnephilidae									
		Pycnopsyche sp.			1	1	1			
	Philopotamidae									
		Chimarra sp.		1	5	1				
	Uenoidae									
		Neophylax sp.		1	5	3				